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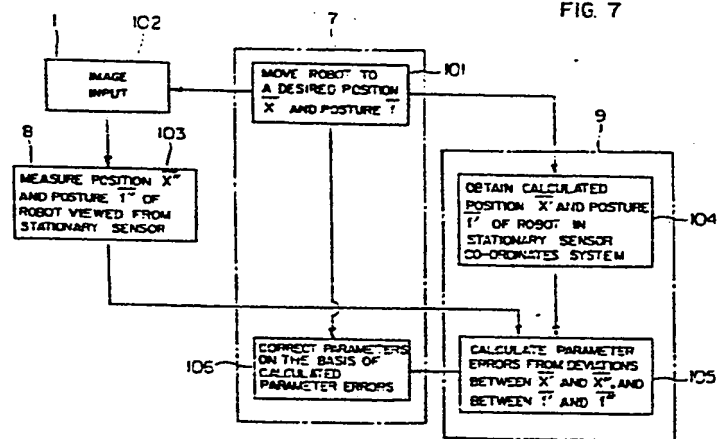
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(54) **Method for correcting systems of coordinates in a robot having visual sensor device and apparatus therefor.**

(57) The co-ordinates system correction apparatus, incorporated in a robot system having a visual sensor for measuring two or three dimensional position and posture data, corrects a visual sensor co-ordinates system and a robot co-ordinates systems. The apparatus corrects the co-ordinates systems by means of a correction of parameters representing a relationship between the co-ordinates systems. The parameter correction is caused by calculating parameter errors from a deviation between calculated position and posture data and measured position and posture data.

FIG. 7



METHOD FOR CORRECTING SYSTEMS OF COORDINATES
IN A ROBOT HAVING VISUAL SENSOR DEVICE
AND APPARATUS THEREFOR

1 BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a control means for a robot having a visual sensor device for
5 measuring a position and posture of an object in a two-
or three-dimension, and more particularly to a co-
ordinates system correction method and apparatus in which
deviations between a visual co-ordinates system and a
robot co-ordinates system are corrected whereby the
10 operation of the robot with the visual sensor device may
be carried out with high accuracy.

DESCRIPTION OF THE PRIOR ART

In general, environmental data from a visual sensor are defined by a proper co-ordinates system fixed
15 to the visual sensor. This is because the position and
posture of an object are detected as the position and
posture of the object in the proper co-ordinates system
fixed to the visual sensor. For instance, Japanese Patent
Publication No. 36374/75 discloses a method for measuring
20 a position of an object by using a television camera in
a triangular surveying manner. Also, in this case, the
position of the object is known by using a co-ordinates
system related to the television camera in accordance
with the obtained video signals.

1 On the other hand, it is convenient for carrying
out various works that the robot works are defined by the
movements of a tool mounted on a wrist of the robot.
Therefore, it is desirable that the movement of the tool
5 is defined in a proper co-ordinates system fixed to the
wrist.

Also, in the case where characteristics of the
robot per se, such as, for example, a speed command value
of the robot are desired to be calculated on the basis of
10 the co-ordinates system proper to the robot body.

Thus, it is desirable to use the co-ordinates
systems proper to the wrist and the body of the robot
and the visual sensor, respectively, in order to control
the operations of the wrist, the body and the visual
15 sensor. However, in the prior art, almost no attempt
has been made to adopt the respective co-ordinate systems.

Thus, in the conventional robot control system,
the respective co-ordinates systems have not been used.
Therefore, the most preferable co-ordinates system has
20 not always been used for the respective structural
components.

In this connection, in the conventional robot
system having a visual sensor, specific data types
corresponding to the respective visual sensor components
25 have been used whereby the data are represented to
variously drive the robot. Therefore, it is necessary
to provide various data types for the various visual
sensor components and prepare various soft wares for

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1 driving the robot. Namely, if, for example, the co-ordinates
system for the visual sensor device is solely used, even
if the same robot body and wrist are used, it is necessary
to reform the overall data system for the co-ordinates
5 system of the visual sensor device. Further, in the prior
art, the specific data system for the various visual
sensor units is used. As a result, upon controlling the
robot, such a difficulty would be encountered that a
command signal for the sensor feedback control in a stand-
10 ardized manner with the robot language is given.

Also, in the prior art, in the case where the
robot is operated by use of the visual sensor, a planar
binary or multivalue image is recognized by the visual
sensor and the handling is carried out in accordance with
15 such a recognition. Therefore, it is only possible to
handle a planar object having a constant posture. At
this time, it is sufficient to consider the parallel
movement on a plane and the rotation in the plane as
errors between the co-ordinates system of the robot and
20 the co-ordinates system of the visual sensor as shown in
USP 3,986,007, and it is relatively easy to correct the
co-ordinates system. Such a correction is carried out
in a recent planar visual sensor device which is available
on the market. However, as the handling operation of the
25 robot is increased and a object having complicated shape
must be handled, it becomes necessary to recognize a
three-dimensional object having a non-fixed position and
posture as well as a planar object. In order to meet

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1 this requirement, there has been proposed a three-
dimensional recognition method using a dual visual sensor
or distant image. In such a three-dimensional visual
sensor, it is necessary to correct spacial errors be-
5 tween the co-ordinates systems of the robot and of the
visual sensor. However, such a technique has never been
proposed or realized.

SUMMARY OF THE INVENTION

An object of the present invention to provide
10 a co-ordinates system correction method capable of
effectively utilizing data from a visual sensor means by
using the respective co-ordinates systems for the respec-
tive structural components and an apparatus for carrying
out the same.

15 Another object of the invention is to provide
a co-ordinates system correction apparatus capable of
readily coping with the position change of the visual
sensor device and/or with the replacement of the visual
sensor device.

20 Still another object of the invention is to
provide a co-ordinates system correction method and
apparatus capable of obtaining with ease and high accuracy
a spacial relationship between the visual sensor co-
ordinates system and at least one of the co-ordinates
25 systems of the robot body and the robot hand.

In order to attain the above-mentioned objects,
according to the invention there is provided a co-ordinates

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1 system correction apparatus in which a co-ordinates
system is setted in at least one of robot body and a
robot hand, the apparatus comprising visual sensor means
to which a proper co-ordinates system is setted, means
5 for detecting a position and/or posture of the object
in the co-ordinate system in the visual sensor means, and
parameter storing means for storing parameters determin-
ing a relationship between the co-ordinates system of
the visual sensor means and at least one of the co-
10 ordinates systems of the robot body and the robot hand,
wherein by using the co-ordinates transformation parameters,
the position and/or posture of the object in the co-
ordinates system of the visual sensor means are trans-
formed into one in the co-ordinates system of the robot
15 hand and/or the co-ordinates system of the robot body,
or transformed into one in the co-ordinates system of the
robot body and further transformed into one in the co-
ordinates system of the robot body.

According to the present invention, transformation
20 parameters are established in the three co-ordinates
systems of the visual sensor means, the robot hand, and
the robot body (or in the two co-ordinates systems if the
co-ordinates systems of the robot hand and the robot
body are the same), so that the environmental data in
25 the proper co-ordinates system established in the visual
sensor means may be used in other co-ordinates system.
Therefore, it is advantageous that the respective co-
ordinates systems may be used for the respective structural

1 components. In addition, the environmental data obtained from the visual sensor means may be effectively used.

According to another aspect of the invention, a plural kinds of the co-ordinates transformation parameters are set and stored in the storing means whereby even if the visual sensor means is replaced by another visual one, the co-ordinates transformation parameters corresponding thereto may be assigned. In accordance with the specific embodiment, since plural kinds of transformation parameters are prepared, any parameter may be assigned corresponding to the various visual sensor means. Such a various correspondence to the various kinds of visual sensor means is actually available. It is necessary to fix the visual sensor means anywhere in the robot body. However, the visual sensor means is not limited to a single visual sensor means, and it is general that the position where the visual sensor means is fixed is different in accordance with an object to be handled. Therefore, it is necessary to install the visual sensor means to a different position in accordance with the respective mounting positions and to use different visual sensor means. It is therefore preferable to assign the corresponding parameters in accordance with the respective positions. As in the embodiment of the invention, if plural kinds of parameters are stored, when the visual sensor means is replaced by new one or changed in its position, it is possible to assign the parameters corresponding to the changes. This is very

1 convenient.

Also, it is necessary to measure the position and posture of the object and direct the robot hand to the posture direction in order to handle the object in
5 any position and posture. To meet this requirement, it is necessary to accurately correct a deviation of the visual sensor co-ordinates system for measuring the position and posture of the object from the robot body or robot hand co-ordinates system in accordance with the
10 parameters. By the way, even if the robot is moved in accordance with the position and posture information measured by the visual sensor device, the robot is moved to a position and posture deviated from the practical position and posture of the object. Therefore, by
15 utilizing this feature inversely, in the robot body and/or robot hand co-ordinates systems, the position and posture of the object known in advance are measured by the visual sensor means, and it is possible to obtain the parameters giving a relationship between the robot
20 visual sensor and the robot body or hand co-ordinates systems from the errors between the measured values and the calculated values. In accordance with the present invention, by using the parameters in this manner, the correction between the robot body or hand co-ordinates
25 system and the visual sensor co-ordinates system may be attained.

1 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing a robot system to which one embodiment of the invention is applied;

5 Fig. 2 is a perspective view showing a co-ordinates system of a visual sensor shown in Fig. 1;

Fig. 3 is a perspective view showing a co-ordinates system fixed to the object shown in Fig. 2;

10 Fig. 4 is a schematic view illustrating a robot system to which a three-dimensional stationary visual sensor device is fixed;

Figs. 5 and 6 are views showing a relationship between the robot co-ordinates system and the stationary visual sensor co-ordinates system;

15 Fig. 7 is a block diagram showing the functions of the components of the system shown in Fig. 4;

Fig. 8 is a view showing one robot system having a three-dimensional visual sensor;

20 Fig. 9 is a view showing a relationship between the robot hand co-ordinates system and the robot visual sensor co-ordinates system;

Fig. 10 is a view showing a relationship between the object and the robot hand with a visual sensor; and

25 Fig. 11 is a block diagram showing the functions of the components of the system shown in Fig. 8.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A preferred embodiment of the invention will

1 now be described with reference to the accompanying drawings.

In Fig. 1, there is shown a robot system provided with a co-ordinates system correction device in accordance with the preferred embodiment. Two visual devices 1 and 2 are provided in this robot system. The stationary visual device 1 is secured to a base 5 on which a robot 3 is installed. The wrist visual device 2 is mounted on a wrist portion of the robot 3. The robot system shown has six degrees of freedom in motion.

In this robot system, the visual devices 1 and 2 may detect a position and a posture of an object 4. A co-ordinates system is set in a robot body. More specifically, stationary co-ordinates XYZ is fixed in a stationary portion between the robot 3 and the base 5. Another co-ordinates system is set in the wrist portion of the robot 3 and is, in particular, composed of co-ordinates $x_h y_h z_h$ of a hand 6. On the other hand, proper co-ordinates systems are established for the visual devices 1 and 2, respectively. Namely, a co-ordinates system $x_1 y_1 z_1$ is fixed for the stationary visual device 1 and a co-ordinates system $x_2 y_2 z_2$ is fixed for the wrist visual device 2.

When the object 4 are detected on the basis of the co-ordinates systems $x_1 y_1 z_1$ and $x_2 y_2 z_2$ by the visual devices 1 and 2 through an image processor 8, the data from the visual devices 1 and 2 on the basis of the visual device co-ordinates systems are transformed into

1 the data on the basis of the co-ordinates systems of the
robot 3 through parameters giving relationships between
the co-ordinates systems of the visual devices 1 and 2,
and the stationary co-ordinates XYZ and the co-ordinates
5 x_h , y_h , z_h of the hand 6. Thus, the data detected by
the visual devices 1 and 2 on the basis of their own
co-ordinates systems are transformed into the data on
the basis of the co-ordinates systems of the robot body
and of the wrist of the robot. The robot operates on the
10 basis of such transformed data. In this manner, the
structural components can desirably operate on the basis
of the respective co-ordinates systems. The above-
described parameters are stored in a parameter storing
means incorporated in a robot control unit 7.

15 In this embodiment, a plural sets of parameters
are provided and stored in the parameter storing means so
as to readily cope with the position changes of the
visual devices and/or the replacement of the visual
devices.

20 The construction and the operation of the
embodiment will now be described in more detail.

As described above, in this embodiment, a
visual sensor system includes two visual devices 1 and 2.
The stationary visual device 1 is fixed to the base 5
25 and the wrist visual device 2 is mounted on the wrist
portion of the robot 3. Each of the visual devices is
composed of, e.g. a camera having a slit light source.
The stationary visual device 1 is a two- or three-

1 dimensional visual sensor and can recognize the position
and the posture of the object 4. For instance, if the
stationary visual device 1 is a two-dimensional visual
sensor, a position \vec{p} of the object 4 in the co-ordinates
5 system fixed to the visual device 1 as shown in Fig. 2 is
defined by the components p_{x1} , p_{y1} , p_{z1} of the x_1 , y_1 , z_1
axes and is expressed in the following equation (1).

$$\vec{p} = p_{x1} \vec{i}_1 + p_{y1} \vec{j}_1 + p_{z1} \vec{k}_1 \quad \dots\dots (1)$$

where \vec{i}_1 , \vec{j}_1 , and \vec{k}_1 are the unit vectors in parallel to
the x_1 , y_1 and z_1 axes, respectively. When the stationary
10 visual device 1 is the two-dimensional sensor, in
general, a direction of the z_1 axis is determined by the
mounting position of the visual sensor and the component
 p_{z1} is a constant. On the other hand, the posture of
the object 4 is expressed by cosine components of the
15 two axes fixed thereto and intersected at a right angle
with each other as shown in Fig. 3. The cosine compo-
nents are given by unit vectors \vec{f} and \vec{g} . When the object
4 shown in Fig. 3 is viewed from above the axis \vec{f} with
the two-dimensional visual sensor, the posture is given
as follows.

$$\vec{f} = \vec{k}_1 \quad \dots\dots (2)$$

$$\vec{g} = g_{x1} \vec{i}_1 + g_{y1} \vec{j}_1 \quad \dots\dots (3)$$

1 If the stationary visual device 1 is of the
three-dimensional type, it is possible to recognize any
positions and postures of the object. In this case, the
9 (nine) parameters of p_{x1} , p_{y1} , ..., g_{y1} , and g_{z1} in
5 the following equations may be detected.

$$\vec{p} = p_{x1} \vec{i}_1 + p_{y1} \vec{j}_1 + p_{z1} \vec{k}_1 \quad \dots (4)$$

$$\vec{f} = f_{x1} \vec{i}_1 + f_{y1} \vec{j}_1 + f_{z1} \vec{k}_1 \quad \dots (5)$$

$$\vec{g} = g_{x1} \vec{i}_1 + g_{y1} \vec{j}_1 + g_{z1} \vec{k}_1 \quad \dots (6)$$

Since the stationary visual device 1 is fixed
to the base 5, the relationship between to co-ordinates
system of the stationary visual device 1 and the stationary
co-ordinates XYZ is unchangeable a fixed manner, and
10 then the cosine components (p_x, p_y, p_z) , (f_x, f_y, f_z) ,
 (g_x, g_y, g_z) of \vec{p} , \vec{f} , \vec{g} in the co-ordinates XYZ are
given by the following relationship with using the data
from the visual device 1.

$$\begin{pmatrix} 1 & 0 & 0 \\ p_x & f_x & g_x \\ p_y & f_y & g_y \\ p_z & f_z & g_z \end{pmatrix} = A \begin{pmatrix} 1 & 0 & 0 \\ p_{x1} & f_{x1} & g_{x1} \\ p_{y1} & f_{y1} & g_{y1} \\ p_{z1} & f_{z1} & g_{z1} \end{pmatrix} \quad \dots (7)$$

where A is a matrix of 4 x 4 and its all elements are
15 constants.

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1 In the same manner, the wrist visual device 2
mounted on the wrist portion of the robot may detect the
position and posture components (p_{x2}, p_{y2}, p_{z2}) , $(f_{x2},$
 $f_{y2}, f_{z2})$, (g_{x2}, g_{y2}, g_{z2}) of the object on the basis
5 of the characteristic co-ordinates system $x_2 y_2 z_2$ fixed
in the visual device 2. Since the visual device 2 is
fixed to the wrist of the robot, the co-ordinates system
of the visual device 2 is in an unchangeable relation
with the co-ordinates x_h, y_h, z_h of the hand 6 also fixed
10 to the wrist portion. The data of the position and
posture of the object from the wrist visual device 2 are
transformed into the data on the basis of the hand co-
ordinates system through the following relationship.

$$\begin{pmatrix} 1 & 0 & 0 \\ p_{xh} & f_{xh} & g_{xh} \\ p_{yh} & f_{yh} & g_{yh} \\ p_{zh} & f_{zh} & g_{zh} \end{pmatrix} = B \begin{pmatrix} 1 & 0 & 0 \\ p_{x2} & f_{x2} & g_{x2} \\ p_{y2} & f_{y2} & g_{y2} \\ p_{z2} & f_{z2} & g_{z2} \end{pmatrix} \dots (8)$$

where B is a matrix of 4 x 4 and its all elements are
15 constants.

As described above, in this embodiment, the
relationship between the co-ordinates system x_1, y_1, z_1
of the stationary visual device 1 and the stationary
co-ordinates system X Y Z is given by the parameters
20 determined by the matrix A. Also, the relationship
between the co-ordinates system x_2, y_2, z_2 of the wrist
visual device 2 and the co-ordinates system x_h, y_h, z_h

1 of the hand 6 is given by the parameters determined by
the matrix B. Therefore, the data which the visual
devices 1 and 2 recognize with their own co-ordinates
systems, respectively, are transformed into the data on
5 basis of the co-ordinates systems of the robot 3 and the
hand 6 fixed to the wrist of the robot 3 through the above-
described parameters. The robot operates on such trans-
formed data. These parameters are stored in the parameter
storing means of the robot control unit 7.

10 The embodied apparatus with such a construction
will operate as follows with respect of the control of
the robot.

 For instance, when it is assumed that the hand
6 of the robot is controlled to be positioned in the
15 same place as the position and the posture of the object
are recognized by the visual sensors. In this case,
it is preferable that the position and posture \vec{p} , \vec{f} , \vec{g}
of the hand 6 be given by the stationary co-ordinates
system. Therefore, when the stationary visual device 1
20 is used, the data from the visual device 1 are multiplied
by the matrix A of parameter and are transformed into
the data on the stationary co-ordinates. This makes it
possible to control the hand 6 by means of usage of such
transformed data. When the wrist visual device 2 is
25 used, in the same manner, the data from the visual device
2 is used, in the same manner, the data from the visual
device 2 are multiplied by the matrix B of parameter
and are transformed into the data on the hand co-ordinates

1 system. In this case, the transformed data may be further transformed into the data on the stationary co-ordinates system by using another parameters. These another parameters may be expressed by a matrix C, the matrix C
5 is of 4 x 4 type and its elements are functions of 6 (six) displacements of a kinematic pair $\theta_1, \theta_2, \dots, \theta_6$, i.e. $c_{ij} = f_{ij}(\theta_1, \theta_2, \dots, \theta_6)$. From the values of \vec{p} , \vec{f} and \vec{g} thus transformed into the stationary co-ordinates system, the displacements of the kinematic pair $\theta_{1f}, \theta_{2f},$
10 \dots, θ_{6f} are calculated, each of which corresponds to the respective transformed values. Then, an actuator for driving the kinematic pair is controlled so that each displacement of the respective pairing elements becomes the corresponding calculated value.

15 An explanation has been made as to the example of a robot system having two visual sensors. However, any number of the visual sensors may be used as far as parameters determining a relationship between the co-ordinates fixed to each visual sensor and the robot co-ordinates are defined. In this case, if the visual
20 sensors are numbered and then the number of a desired visual sensor is called out by a robot language or the like, the control unit 7 generates a drive signal to the desired visual sensor. Then, the data from visual
25 sensors are multiplied by a matrix (parameters) stored in advance and corresponding to the called visual sensor, so that the data for controlling the robot may be obtained.

As described above, in the co-ordinates system

1 correction apparatus in accordance with this embodiment,
since the visual devices 1 and 2 are provided with the
respective co-ordinates system therefor and the
relationships between the sensor co-ordinates systems
5 and the robot co-ordinates systems are determined by
the matrixes, the same drive soft ware may control the
robot in accordance with each signal of the sensors even
for the robot system having a plurality of visual sensors.
Therefore, it is possible to standardize the drive soft
10 ware. Also, if the matrices each corresponding to
the respective sensors are stored in the control unit 7
in advance, it is possible to carry out the feedback
control of the robot simply by calling the desired
sensor number in terms of the robot language. A compli-
15 cated robot language command may not be required. Further,
if the parameters for data transformation are represented
in a matrix form, it is possible to attain a high speed
calculation through an array processor. If the matrix
is simple, it is of course possible to make the data
20 transformation through a particular sub-routine.

In the preceding embodiments, although there
is not shown a specific method for obtaining the trans-
formation matrixes A or B in the case where the visual
device 1 or 2 is of a three-dimensional visual sensor
25 type, the co-ordinates system correction apparatus in
accordance with the present invention may be used for
that case. A method for obtaining the matrix A will
now be described in accordance with another embodiment.

1 Fig. 4 is an illustration of one embodiment showing a parameter measuring method in relation to a three-dimensional visual sensor. Fig. 5 is a schematic view showing a relationship between the robot and the stationary visual sensor. Fig. 6 shows a relationship between the co-ordinates systems of the robot and the stationary visual sensor. Fig. 7 is a block diagram illustrating functions of components of the embodiment shown in Fig. 4.

10 In these figures, a reference numeral 1 designates a stationary visual device or sensor fixedly mounted onto a base 5 on which a robot 3 is installed. The robot 3 is provided at a distal end portion thereof with a hand 6. The stationary visual device 1 and the robot, 3 are associated with a robot control unit 8, an image processor 8, and a parameter calculator 9.

20 It is assumed, as shown in Fig. 5 that the \vec{O}_R is an origin of the robot co-ordinates system comprising the axes of \vec{x}_R , \vec{y}_R and \vec{z}_R , and the \vec{O}_V is an origin of the stationary visual sensor co-ordinates system comprising the axes of \vec{x}_V , \vec{y}_V and \vec{z}_V , the relationship between the robot co-ordinates system and the stationary visual sensor co-ordinates system may be expressed by the following equations:

$$\begin{aligned} \vec{O}_V &= \vec{O}_R + L_x \vec{x}_V + L_y \vec{y}_V + L_z \vec{z}_V \\ &= \vec{O}_R + \vec{L} \begin{bmatrix} \vec{x}_V \\ \vec{y}_V \\ \vec{z}_V \end{bmatrix} \end{aligned} \quad \dots (9)$$

$$\begin{bmatrix} \vec{x}_V \\ \vec{y}_V \\ \vec{z}_V \end{bmatrix} = M_\gamma M_\beta M_\alpha \begin{bmatrix} \vec{x}_R \\ \vec{y}_R \\ \vec{z}_R \end{bmatrix} = M \begin{bmatrix} \vec{x}_R \\ \vec{y}_R \\ \vec{z}_R \end{bmatrix} \quad \dots (10)$$

- 1 where $\vec{L} = (L_x, L_y, L_z)$ is a vector representing the displacement from the origin \vec{O}_R of the robot co-ordinates system to the origin \vec{O}_V of the stationary visual sensor co-ordinates system, and M_γ , M_β , and M_α are matrixes
- 5 representing the three rotational displacements between the co-ordinate systems. These matrixes are expressed as follows, when angles of rotation α , β , and γ are selected as shown in Fig. 6:

$$M_\alpha = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{bmatrix}, \quad M_\beta = \begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix},$$

$$M_\gamma = \begin{bmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \dots (11)$$

- The robot control unit 7 commands the robot 3 to
- 10 move to the position $\vec{X} = (x, y, z)$ and posture $\vec{f} = (f_x, f_y, f_z)$ in terms of the robot co-ordinates system. If the parameters L_x , L_y , L_z , α , β , and γ are the same values as the designed one and include no error, the robot must be moved to the following points:

$$\vec{X} = x \vec{x}_R + y \vec{y}_R + z \vec{z}_R + \vec{O}_R \quad \dots (12)$$

$$\vec{f} = f_x \vec{x}_R + f_y \vec{y}_R + f_z \vec{z}_R \quad \dots (13)$$

1 To the contrary, in case that these position
and the posture are calculated with using the data from
the stationary visual sensor 1 and the calculated position
and posture are expressed as $\vec{X}' = (x', y', z')$, $\vec{f}' =$
5 $(f_{x'}, f_{y'}, f_{z'})$.

$$\vec{X}' = x' \vec{x}_V + y' \vec{y}_V + z' \vec{z}_V + \vec{O}_V \quad \dots (14)$$

$$\vec{f}' = f_{z'} \vec{x}_V + f_{y'} \vec{y}_V + f_{z'} \vec{z}_V \quad \dots (15)$$

The relationships between x, y, z and x', y', z' , and
between f_x, f_y, f_z and $f_{x'}, f_{y'}, f_{z'}$, are determined from
the equations (9) to (11).

However, if the stationary visual sensor 1 is
10 not accurately mounted on the predetermined portion of
the robot system, the errors are expressed as ΔL_x of L_x ,
 ΔL_y , ΔL_z , $\Delta \alpha$, $\Delta \beta$, and $\Delta \gamma$. In this case, the parameters
in the equations (9) to (11) become $(L_x + \Delta L_x)$, $(\alpha + \Delta \alpha)$
and the like. Therefore, even if the robot is commanded
15 to move to $\vec{X} = (x, y, z)$, $\vec{f} = (f_x, f_y, f_z)$, the robot
can not reside in the position and posture $\vec{X}' = (x', y',$
 $z')$, $\vec{f}' = (f_{x'}, f_{y'}, f_{z'})$ but in $\vec{X}'' = (x'', y'', z'')$,
 $\vec{f}'' = (f_{x''}, f_{y''}, f_{z''})$ which are deviated from \vec{X}' , \vec{f}' .
Therefore, if the respective deviations between x', y' ,

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1 z' and x'' , y'' , z'' , and between $f_{x'}$, $f_{y'}$, $f_{z'}$ and $f_{x''}$, $f_{y''}$,
 $f_{z''}$ are measured, ΔL_x , ΔL_y , ΔL_z , $\Delta \alpha$, $\Delta \beta$, $\Delta \gamma$ may be
obtained from the equations (9) to (11).

The construction and operation of the embodiment
5 shown in Fig. 4 will now be described with reference to
Fig. 7.

The robot 3 is moved in accordance with the
position and posture command vectors \vec{X} , \vec{F} from the robot
control unit 7 (step 101). The stationary visual sensor
10 1 picks up an image of the robot 3 after the movement
thereof and feed the image information to the image
processor 8 (step 102). The position and posture \vec{X}'' , \vec{F}''
of the robot 3 as viewed from the stationary visual
sensor 1 are measured in the image processor 8 (step 103).
15 On the other hand, the parameter calculator 9 calculates
the position and posture \vec{X}' , \vec{F}' (equations (14) and (15))
in the stationary visual co-ordinates system by using
the equations (9), (10) and (11) on the basis of the
command signals or vectors \vec{X} , \vec{F} from the robot control
20 unit 7 (step 104). If the stationary visual sensor 1 is
accurately mounted on the predetermined portion of the
robot system, the position \vec{X}'' and posture \vec{F}'' of the
robot measured by the stationary sensor 1 coincide with
the calculated position \vec{X}' and posture \vec{F}' of the robot.
25 To the contrary, if the stationary sensor 1 is not
accurately mounted on the predetermined portion of the
robot system, the measured position \vec{X}'' and posture \vec{F}''
are deviated from the calculated position \vec{X}' and posture

1 \vec{f}' by some deviations caused by such unaccurate mounting
of the robot. Namely, the measured position \vec{x}'' and
posture \vec{f}'' have the deviations from the practical
position and posture of the robot, which are caused by
5 the parameter errors, e.g. ΔL_x . Accordingly, the correct
parameters may be obtained from the respective deviations
between \vec{x}' and \vec{x}'' , and between \vec{f}' and \vec{f}'' (steps 105,
106).

Also, in the above-described measurement of the
10 parameters, even if the visual device is fixed to the
wrist of the robot as the visual sensor 2, the matrix B
may be obtained in the same manner.

Fig. 8 is a schematic view illustrating one
embodiment of a robot system having a three-dimensional
15 movable visual sensor, Fig. 9 shows the relationship
between the robot hand co-ordinates system and the robot
visual sensor co-ordinates system, Fig. 10 shows the
relationship between the object and the robot hand with
the visual sensor more specifically, and Fig. 11 is a
20 block diagram showing the functions of the components of
the system shown in Fig. 8.

In these figures, a reference numeral 2
designates a wrist visual sensor mounted on a distal end
portion of the robot for sensing an object 4 to be measured.
25 The other elements and components are the same as shown
in Fig. 4.

As shown in Fig. 9, the parameters to be used
upon mounting the robot wrist visual sensor 2 on the robot

- 1 wrist include 6 (six) parameters such as a vector $\vec{L} = (L_x, L_y, L_z)$ representing a displacement between the origin \vec{O}_h of the robot hand co-ordinates system and the origin \vec{O}_v of the robot wrist visual sensor co-ordinates system,
- 5 and angles of rotation α, β, γ representing the respective rotational displacement between the corresponding axes of the co-ordinates systems. In this case, the relationships between the origin \vec{O}_h of the robot hand co-ordinates system and the origin \vec{O}_v of the wrist visual sensor co-
- 10 ordinates system, and between the axes $\vec{x}_h, \vec{y}_h, \vec{z}_h$ of the robot hand co-ordinates system and the axes $\vec{x}_v, \vec{y}_v, \vec{z}_v$ of the wrist visual sensor co-ordinates system are represented by the following equations:

$$\vec{O}_v = \vec{O}_h + L_x \vec{x}_h + L_y \vec{y}_h + L_z \vec{z}_h \quad \dots (16)$$

$$\begin{bmatrix} \vec{x}_v \\ \vec{y}_v \\ \vec{z}_v \end{bmatrix} = M_\gamma M_\beta M_\alpha \begin{bmatrix} \vec{x}_h \\ \vec{y}_h \\ \vec{z}_h \end{bmatrix} = M \begin{bmatrix} \vec{x}_h \\ \vec{y}_h \\ \vec{z}_h \end{bmatrix}, \quad M = M_\gamma M_\beta M_\alpha \quad \dots (17)$$

- where M_α, M_β and M_γ are the 3x3 matrixes representing the
- 15 rotations about \vec{x}_h, \vec{y}_h and \vec{z}_h , respectively, and are given as follows:

$$M_\alpha = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha & \sin \alpha \\ 0 & -\sin \alpha & \cos \alpha \end{bmatrix},$$

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$$M_{\beta} = \begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix}$$

$$M_{\gamma} = \begin{bmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

.... (18)

- 1 As shown in Fig. 10, if the normal vector fixed to the object 4 as viewed from the robot wrist visual sensor co-ordinates system is expressed as $\vec{f} = (f_x^V, f_y^V, f_z^V)$, the following equation is obtained:

$$\vec{f} = f_x^V \vec{x}_V + f_y^V \vec{y}_V + f_z^V \vec{z}_V$$

.... (19)

- 5 In order to express this vector in terms of the robot hand co-ordinates system, the vector is transformed into the following equation by expressing $\vec{x}_V, \vec{y}_V, \vec{z}_V$ by $\vec{x}_h, \vec{y}_h, \vec{z}_h$ in accordance with the equations (17) and (18):

$$\vec{f} = f_x^R \vec{x}_h + f_y^R \vec{y}_h + f_z^R \vec{z}_h$$

.... (20)

- where the normal vector as viewed from the robot hand co-ordinates system is expressed by $\vec{f} = (f_x^R, f_y^R, f_z^R)$.

Also, when a point on the object 4 is viewed from the visual sensor co-ordinate system, if the point is viewed as $\vec{X} = (x_V, y_V, z_V)$, the following equation is given:

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.... (21)

$$\vec{X} = x_v \vec{x}_v + y_v \vec{y}_v + z_v \vec{z}_v$$

- 1 If the scaling ratios of the television camera of the robot wrist visual sensor 2 are expressed by s_x, s_y, s_z with respect to the respective directions $\vec{x}_v, \vec{y}_v, \vec{z}_v$, \vec{X} is viewed from the robot wrist co-ordinate system, and is expressed in accordance with the equation (16) as follows:

$$\vec{X} = L_x \vec{x}_h + L_y \vec{y}_h + L_z \vec{z}_h + s_x x_v \vec{x}_v + s_y y_v \vec{y}_v + s_z z_v \vec{z}_v \quad \dots (22)$$

- $\vec{x}_v, \vec{y}_v, \vec{z}_v$ in this equation are represented by $\vec{x}_h, \vec{y}_h, \vec{z}_h$ in accordance with the equations (17) and (18) and are substituted thereby. Then, the following equation is given:

$$\vec{X} = x_h \vec{x}_h + y_h \vec{y}_h + z_h \vec{z}_h \quad \dots (23)$$

If the equation (22) is thus transformed, the fixed point as viewed from the robot wrist co-ordinate system is positioned as $\vec{X} = (x_h, y_h, z_h)$.

- As potential errors which would be generated when the robot wrist visual sensor 2 is mounted on the robot hand, errors $\Delta L_x, \Delta L_y, \Delta L_z, \Delta \alpha, \Delta \beta, \Delta \gamma$ would be considered with respect to $L_x, L_y, L_z, \alpha, \beta, \gamma$, respectively. When these errors would be present, the parameters in the

1 equations (16) to (18) such as L_x are replaced by $(L_x + \Delta L_x)$ and the like. In this case, the equations (16) and (17) may be rewritten as follows:

$$\begin{bmatrix} \vec{O}_v \\ \vec{x}_v \\ \vec{y}_v \\ \vec{z}_v \end{bmatrix} = G \begin{bmatrix} \vec{O}_h \\ \vec{x}_h \\ \vec{y}_h \\ \vec{z}_h \end{bmatrix}, \quad G = \begin{bmatrix} g_{11} & g_{12} & g_{13} & g_{14} \\ g_{21} & g_{22} & g_{23} & g_{24} \\ g_{31} & g_{32} & g_{33} & g_{34} \\ g_{41} & g_{42} & g_{43} & g_{44} \end{bmatrix} \quad \dots (24)$$

The element g_{ij} of the matrix G includes errors ΔL_x and the like. If g_{ij} is known, ΔL_x , ΔL_y , ΔL_z , $\Delta \alpha$, $\Delta \beta$, $\Delta \gamma$ may be known by conducting suitable calculations.

Unless errors exist, the object 4 which resides in a position $\vec{X} = (x_v, y_v, z_v)$ and in a posture $\vec{f} = (f_x^v, f_y^v, f_z^v)$ as viewed through the robot wrist visual sensor 2 may reside in a position $\vec{X} = (x_h, y_h, z_h)$ and a posture $\vec{f} = (f_x^R, f_y^R, f_z^R)$ as viewed through the robot hand co-ordinates. However, actually, due to the errors such as ΔL_x , it is measured that the object 4 resides in a position $\vec{X}' = (x'_h, y'_h, z'_h)$ and in a posture $\vec{f}' = (f_x^{R'}, f_y^{R'}, f_z^{R'})$. By these deviations of the position and posture, the equations (16) and (17) are deformed into the equation (24). Accordingly, by measuring the deviations in position and posture, it is possible to determine the elements g_{ij} of the matrix G . If the elements g_{ij} are known, the errors such as ΔL_x may be obtained.

1 The construction and operation of the specific
embodiment will now be described with reference to Figs.
8 and 11.

 The robot 3 is moved close to the fixed point
5 on the object 4 in accordance with the command signals
of the position and posture from the robot control unit
7 (step 201). Thereafter, the image information is
inputted into the robot wrist visual sensor 2 and fed to
the image processor 8 (step 202). The position and
10 posture \vec{X}' and \vec{f}' are measured in the image processor 8
(step 203).

 On the other hand, the position and posture of
the fixed point on the object is inputted in advance in
the parameter calculator 9 (step 204). On the basis of
15 the wrist position and posture information (step 205)
from the robot control unit 7, the position and posture
 \vec{X} and \vec{f} of the fixed point as viewed from the robot wrist
visual sensor co-ordinates system are calculated in
accordance with the equations (16), (17) and (18) (step
20 206). Upon the calculation of \vec{X} , \vec{f} , it is made on the
basis of that there is no error in the parameters whereas
the \vec{X}' , \vec{f}' measured by the robot wrist visual sensor 2
include the parameter errors. Therefore, the vectors \vec{X}
and \vec{X}' and \vec{f} and \vec{f}' are different from each other. Then,
25 if the matrix G in the equation (24) is obtained in
accordance with \vec{X}' , \vec{f}' (step 207), the parameters included
in the respective components of the matrix G include
errors. Accordingly, by comparing the parameters in the

1 equations (16) and (17) to the parameters in the matrix
G, it is possible to obtain the parameter errors (step
208).

As described above, in accordance with the
5 present invention, in a co-ordinate system correction
apparatus including visual sensor means for detecting
a position and/or posture of an object, the apparatus
comprises means for setting a co-ordinate system in at
least one of a robot body and a robot wrist, setting a
10 proper co-ordinate system in the visual sensor means and
detecting the position and/or posture of the object in the
co-ordinate system in the visual sensor means, and para-
meter storing means for storing parameters determining a
relationship between the co-ordinate system of the
15 visual sensor means and at least one of the co-ordinate
systems of the robot body and the robot wrist. By using
the co-ordinate transformation parameters, the position
and/or posture of the object in the co-ordinate system
of the visual sensor means are transformed into the
20 co-ordinate system of the robot wrist and the co-ordinate
system of the robot body, or otherwise into the co-ordinate
system of the robot body and further transformed into the
co-ordinate system of the robot body. Accordingly, the
respective structural elements such as the visual sensor
25 means are operated by the respective co-ordinate systems.
Thus, by the operation in a desired condition, it is
advantageous that the obtained data are effectively
utilized. Also, it is easy to carry out the co-ordinate

1 transformation with the parameters. By storing the
parameters in the parameter storing means, it is possible
to always correspond to the transformation of the data
from the visual sensor means.

5 Furthermore, according to the invention, by
preparing and using a plurality of parameters, it is
possible to correspond to the case where the visual
sensor is changed in position and another visual sensor
is used.

10 Also, it is possible to construct the robot
system so as to command the robot in a standardized manner
with a simple robot language.

Moreover, in accordance with the present
invention, since three-dimensional mounting parameters
15 generated when the visual sensor is fixed to the robot
co-ordinates system may be obtained by moving the robot,
the following meritorious advantages can be obtained.

(1) By obtaining the three-dimensional mounting
parameters and using them, it is possible to handle with
20 high accuracy a three-dimensional object taking any
position and posture as well as a planar object by means
of the visual sensors.

(2) Also, the mounting parameters may be
obtained simply by measuring the object while moving the
25 robot. Accordingly, the correction work can be made
more readily than the measurement of the mounting para-
meters with a measuring tools. This leads to enhancement
in accuracy of the robot operation and in efficiency.

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- 1 It is apparent that the present invention is not limited to the embodiments shown but various changes or modification are possible for those skilled in the art.

CLAIMS

1. A robot system having a visual sensor comprising:
a robot having a first co-ordinates system
provided in at least one of a robot body and a robot
hand;

a visual sensor device having a second co-
ordinates system for detecting a position and/or posture
of an object;

means for measuring parameters determining a
relationship between said second co-ordinates system and
said first co-ordinates system;

means for storing said parameters measured by
means of said measuring means; and

means for transforming a detected position and/or
posture information of the object in said second co-
ordinates system into an information in said first co-
ordinates system through said measured parameters.

2. A robot system as claimed in Claim 1, wherein
said parameters for co-ordinates transformation includes
a plurality of sets of parameters each set corresponding to
a respective visual sensor devices whereby a corresponding
co-ordinates transformation parameter set may be assigned
even if the visual sensor device is replaced by another
visual sensor device.

3. A robot system as claimed in Claim 2, wherein
said co-ordinates transformation parameter sets include
one for a visual sensor device mounted on said robot
hand and one for a visual sensor device mounted fixedly

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on a base on which said robot is installed.

4. A robot system as claimed in Claim 1, wherein said co-ordinates transformation parameters are determined by a matrix.

5. A robot system as claimed in Claim 1, wherein said first co-ordinates system is established in said robot hand, and after an information in said second co-ordinates system is transformed into an information in said first co-ordinates system, said transformed information is further transformed into an information in a co-ordinates system of said robot body.

6. A robot system as claimed in Claim 1, wherein said parameter measuring means comprises:

first means for moving said robot to a fixed point on the fixed object to be measured with said robot being kept in a constant position and posture, and for calculating a position and posture of said robot hand moved said fixed point,

second means for measuring a position and posture of said fixed point with a visual sensor device, and

third means for calculating co-ordinates transformation parameters by means of data obtained by said first means and of data obtained by said second means.

7. A robot system as claimed in Claim 6, wherein said visual sensor device includes a wrist visual sensor device mounted on said robot hand.

8. A robot system as claimed in Claim 1, wherein

said parameter measuring means comprises:

first means for moving said robot to a commanded position and for calculating a position and posture in said commanded position,

second means for measuring a position and posture of said robot after movement through said visual sensor device, and

third means for calculating co-ordinates transformation parameters by means of said calculation result obtained by said first means and of said measurement result obtained by said second means.

9. A robot system as claimed in Claim 8, wherein said visual sensor device includes a stationary visual sensor device fixed to a base on which said robot is installed.

10. A co-ordinates system correction apparatus comprising:

a robot having a first co-ordinates system provided in at least one of a robot body and a robot hand;

a visual sensor device mounted on a distal end portion of said robot or a base on which said robot is installed, said visual sensor device having a second co-ordinates system and a function for measuring a position and/or a posture of an object;

visual data storing means for storing a position and/or a posture information measured by said visual sensor device,

robot data storing means for storing data representing a position and/or a posture of said robot in said first co-ordinates system when said visual data are measured;

parameter measuring means for measuring parameters giving a relationship between said first co-ordinates system and said second co-ordinates system by means of said visual data storing means and said robot data storing means;

parameter storing means for storing said measured parameters; and

means for transforming an information of a position and/or a posture of an object in said second co-ordinates system into an information in said first co-ordinates system by using said parameters.

11. A method for correcting a robot visual sensor co-ordinates system for a robot system including a robot, a stationary visual sensor device fixed close to said robot, an image processor for processing image data from said sensor device, an error calculating device and a robot control unit for controlling and processing said components and data, said method comprising the steps of:

moving said robot to a commanded position under a control of said robot control unit,

measuring a position and posture of said robot in a stationary visual sensor co-ordinates system by means of said stationary visual sensor device and said image processor after movement of said robot,

calculating a commanded position and posture of said robot in said stationary visual sensor co-ordinates system by means of said error calculating device,

calculating errors in mounting said stationary visual sensor device from a deviation between said calculated and said measured position and posture of said robot, and

correcting the deviation between a robot co-ordinates system and said stationary visual sensor co-ordinates system, which caused by said mounting errors.

12. A method for correcting a robot wrist visual sensor co-ordinates system for a robot system including a robot, a sensor device mounted on a robot wrist, an image processor for processing image data from said wrist sensor device, a mounting error measuring device and a robot control unit for controlling and processing said components and data, said method comprising the steps of:

moving said robot to a commanded point close to a fixed point of a stationary object to be measured. fixed in a constant position and posture under a control of said robot control unit,

calculating a position and posture of said robot hand,

measuring a position and posture of said fixed point in a robot wrist visual sensor co-ordinates system

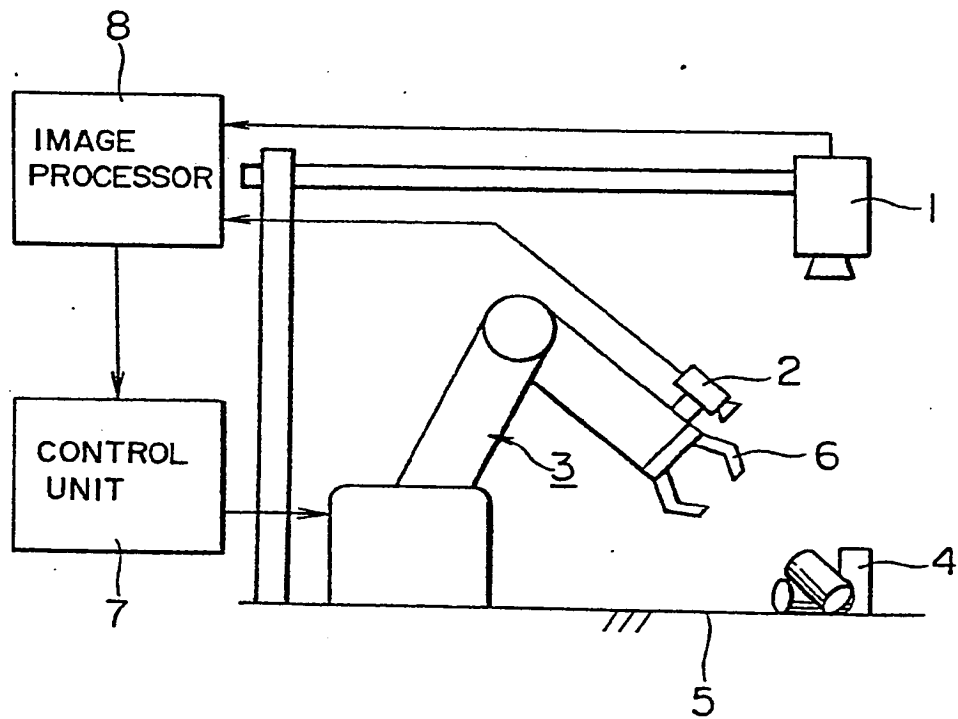
by means of said robot wrist visual sensor device and said image processor,

--calculating mounting errors of said robot wrist visual sensor from said measured and said calculated position and posture of said robot wrist by means of said mounting error calculating device, and

correcting a deviation between said robot wrist co-ordinates system and said robot wrist visual sensor co-ordinates system.

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FIG. 1



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FIG. 2

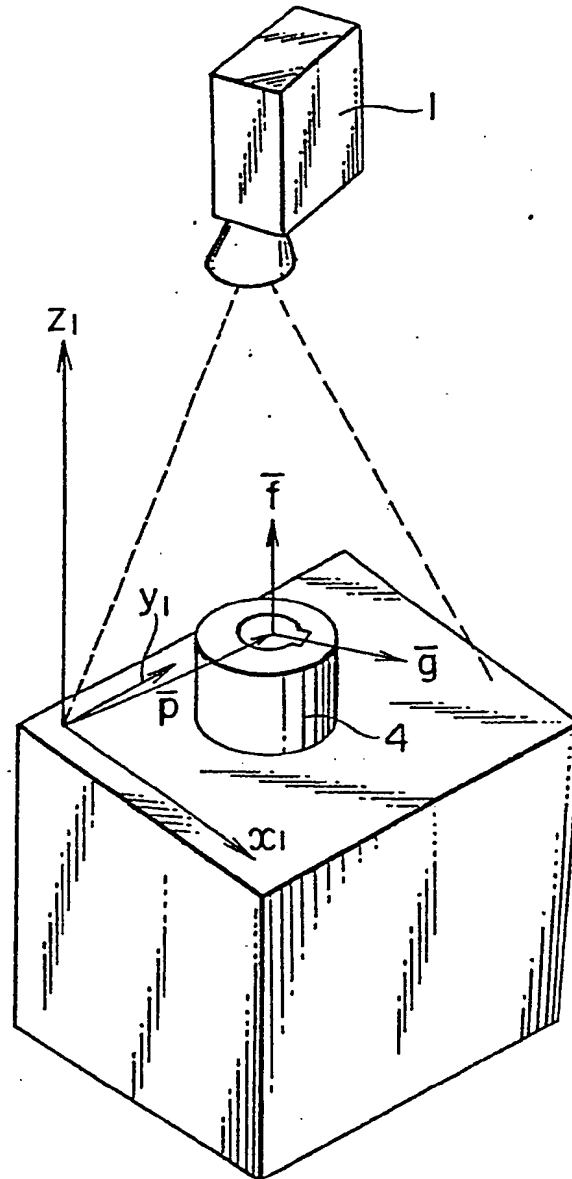


FIG. 3

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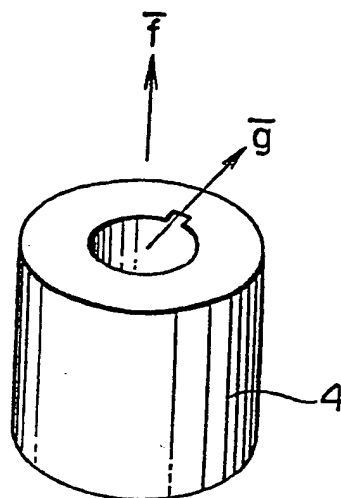


FIG. 4

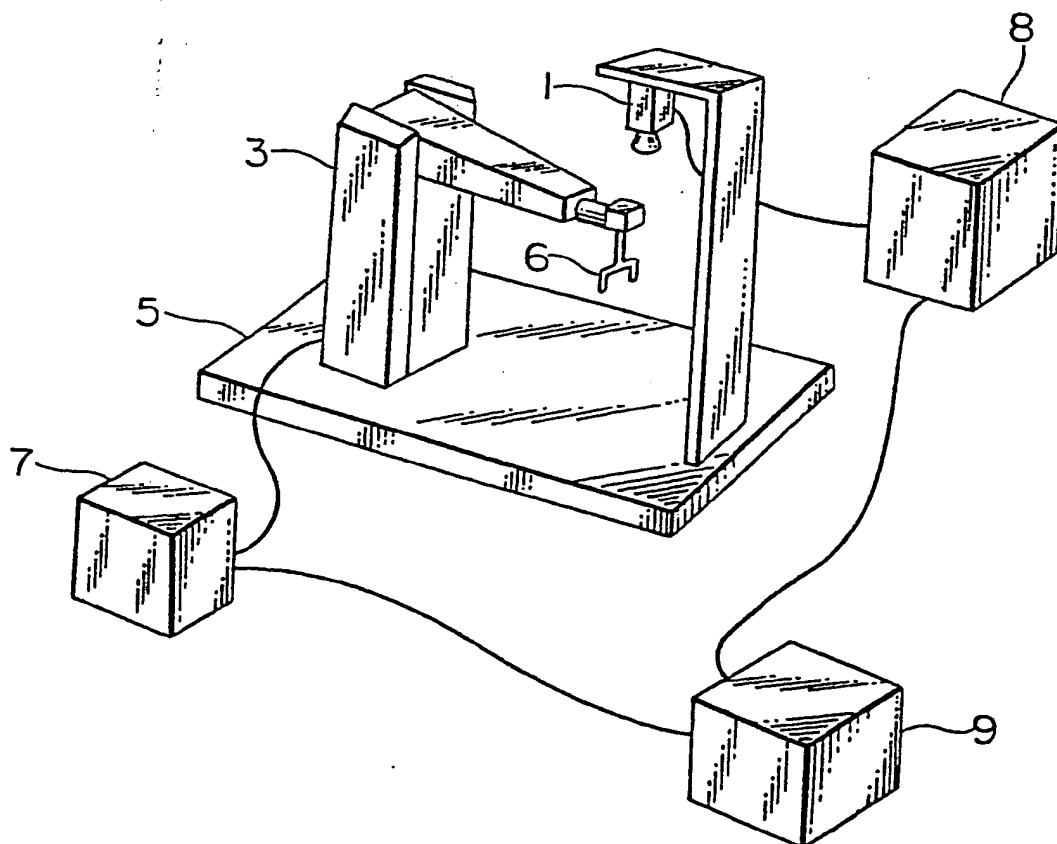


FIG. 5

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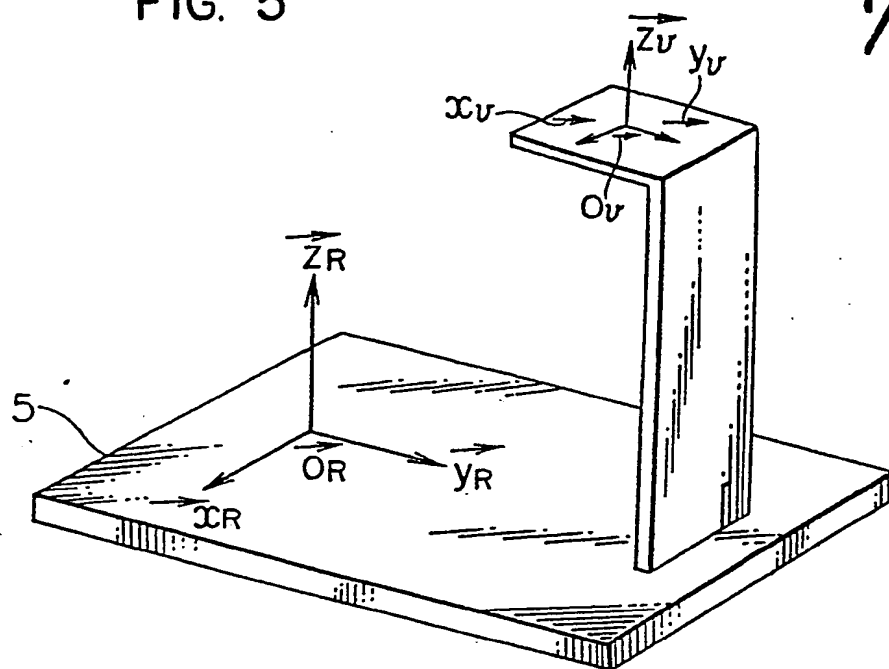
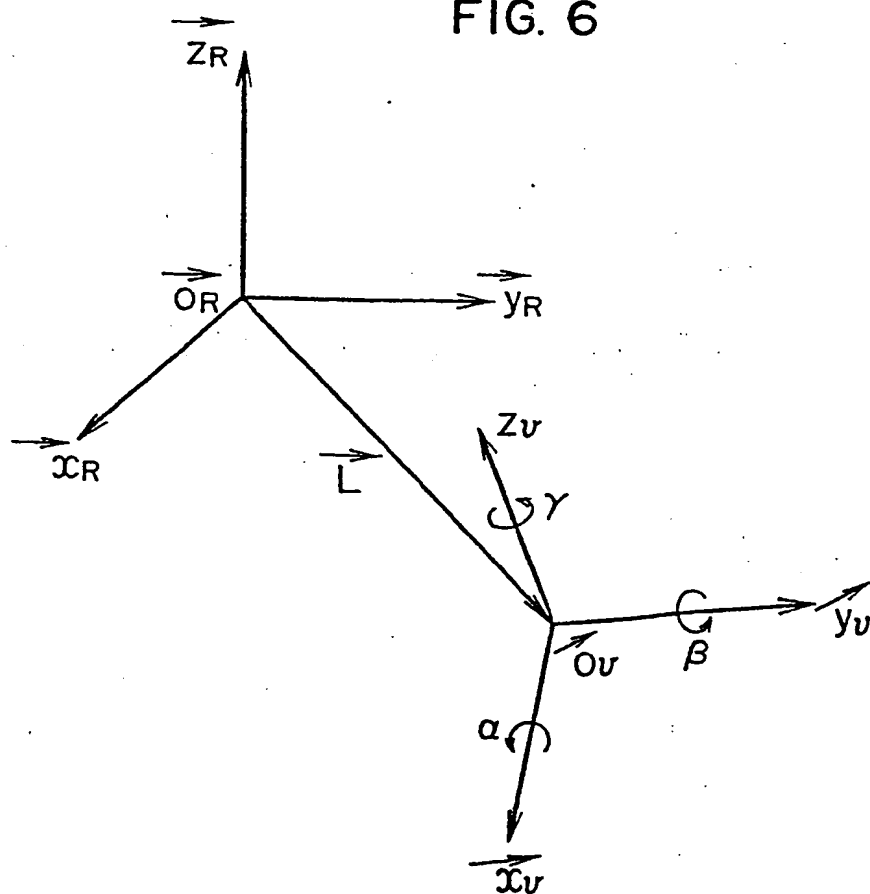
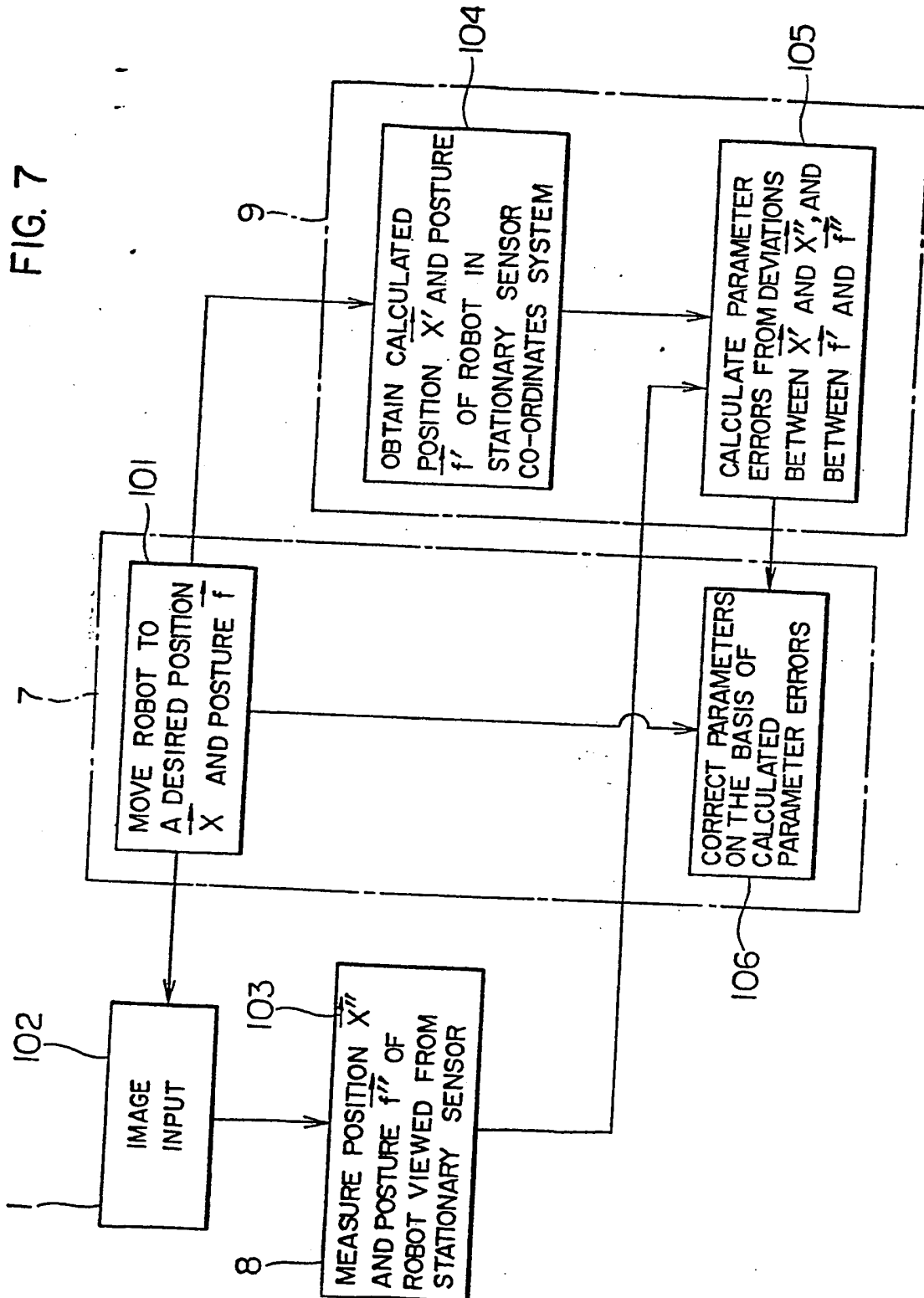


FIG. 6

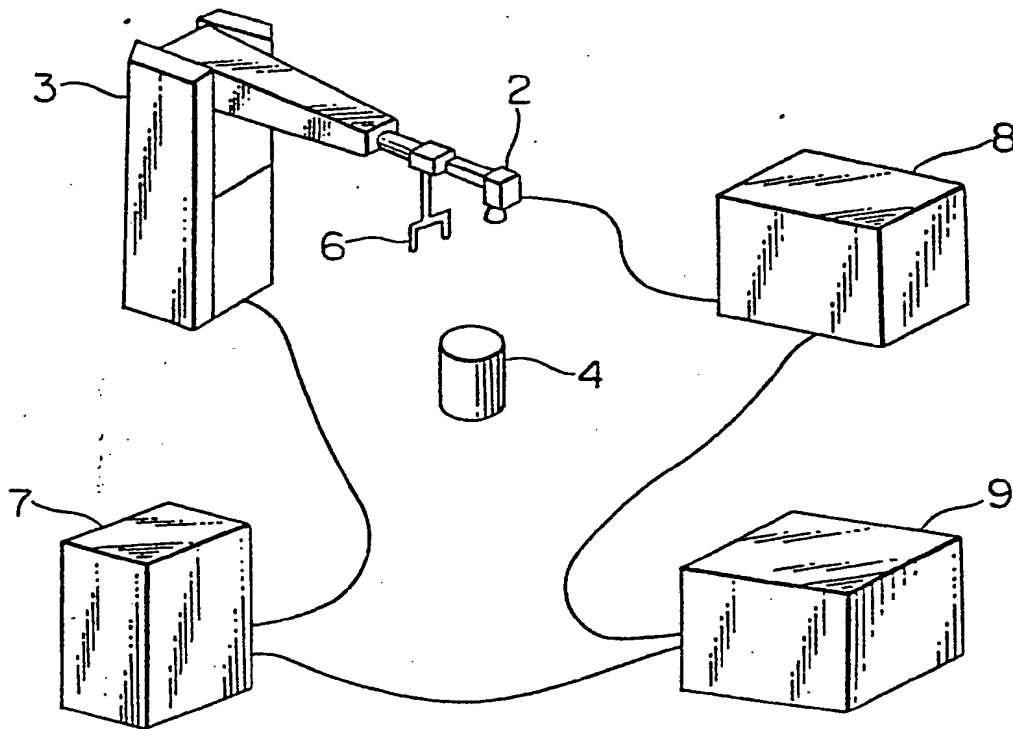




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FIG. 8



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FIG. 9

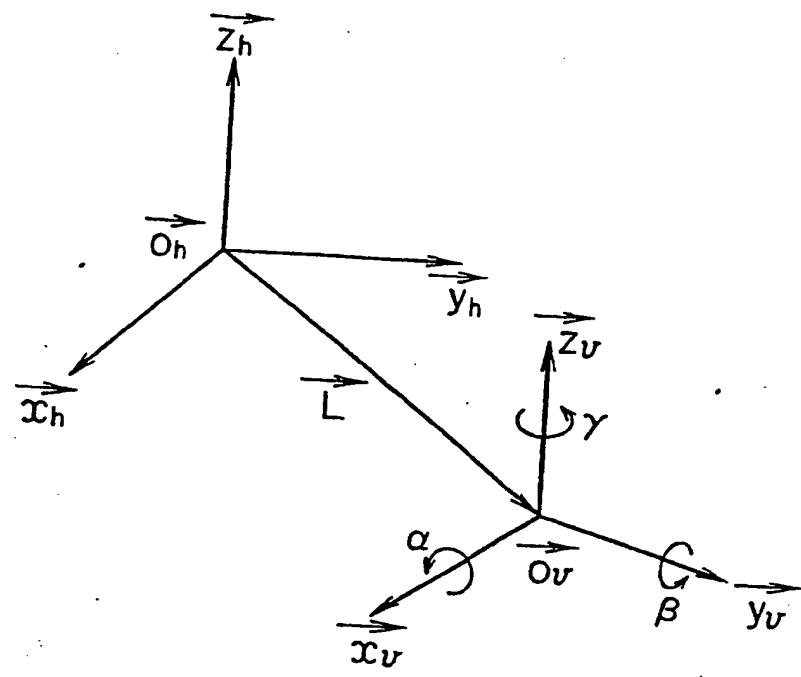


FIG. 10

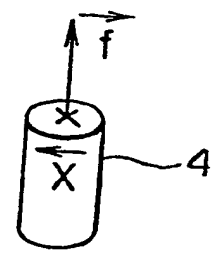
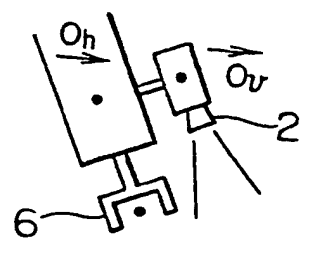
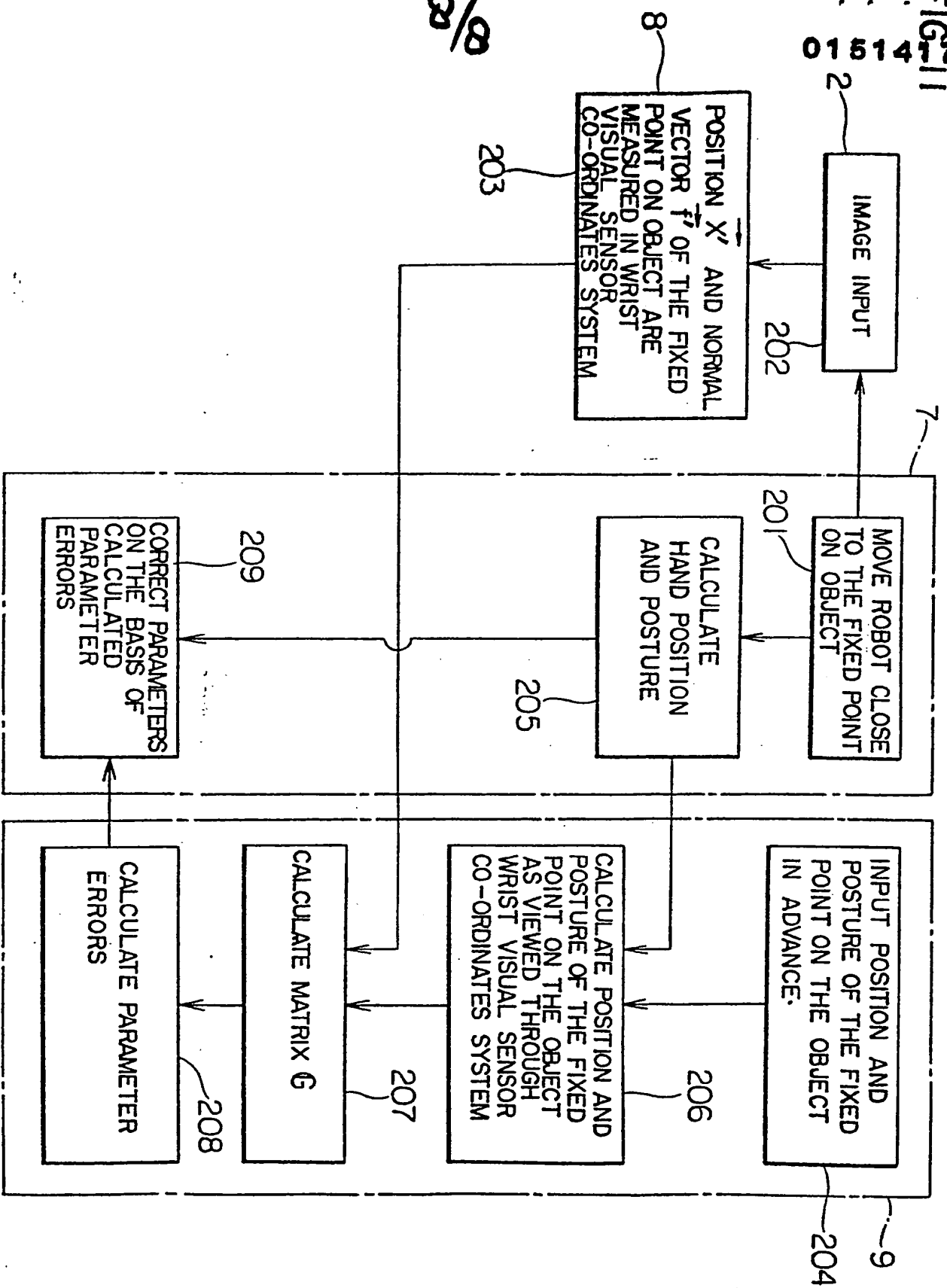


FIG. 1

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A	--- LE NOUVEL AUTOMATISME, vol. 26, nos. 1/2, January/February 1981, pages 53-60; J.-N. FOULC et al.: "Initiation à la robotique. 4-équipement sensoriel et de préhension des manipulateurs" * Pages 53-60 * -----	1	
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Place of search THE HAGUE		Date of completion of the search 26-04-1985	Examiner RESSENAAR J.P.
CATEGORY OF CITED DOCUMENTS			
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Y	--- US-A-4 412 293 (KELLEY) * Whole document *	1-12	
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